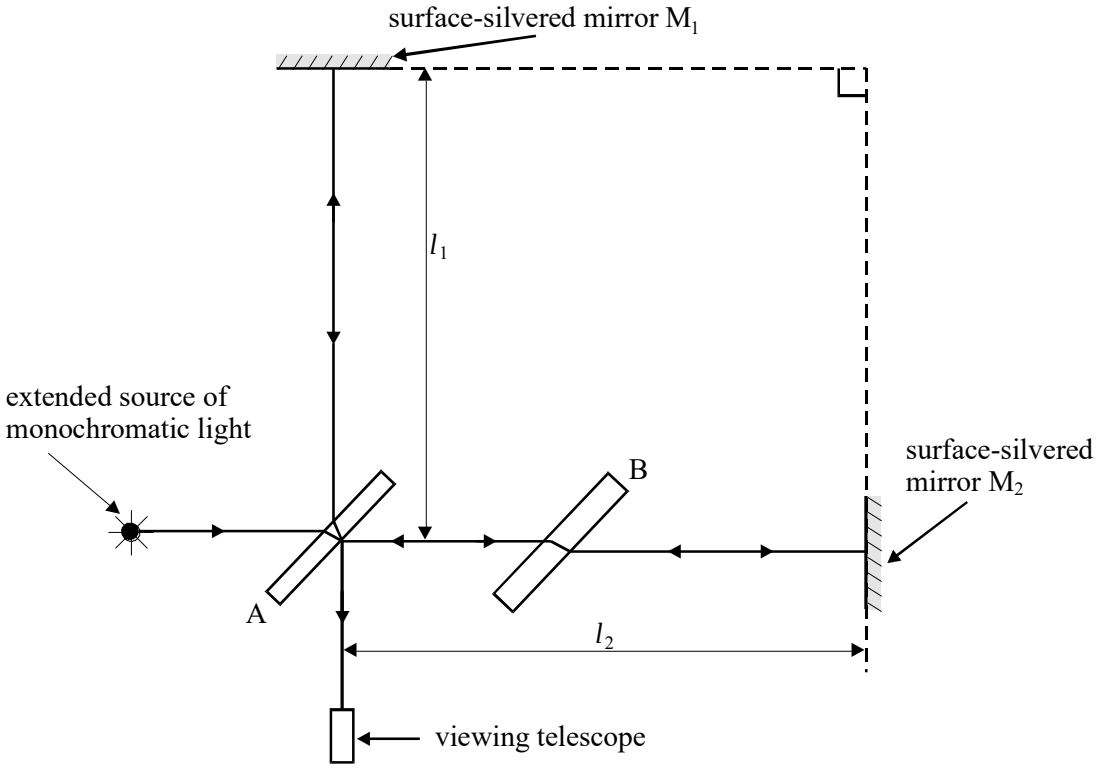
1. The diagram represents the Michelson-Morley interferometer.



(a) (i) Name the object labelled A.

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(ii) Name the object labelled B and explain its purpose.

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(3)

(b) Describe and explain what is observed through the viewing telescope

(i) when distances l_1 and l_2 are equal,

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(ii) as distance l_1 is made slightly longer than distance l_2.

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(4)

(c) Michelson and Morley used the interferometer to try to detect the motion of the Earth through the hypothetical ether.

(i) Outline how the apparatus was used and state what the result was.

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(ii) Explain the significance of the result.

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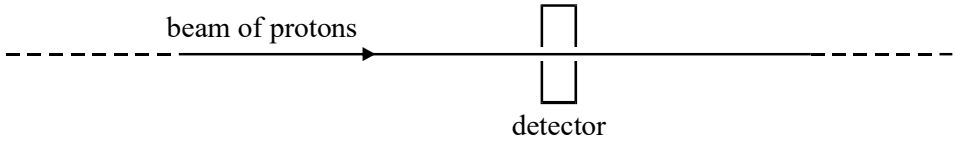
(3)
(Total 10 marks)

2. In a particle beam experiment, a pulsed beam of protons at a speed of 1.00×10^8 m s^{-1} passed through a stationary detector in a time of 15.0 ns.



(a) Calculate the length of the pulsed beam in

(i) the frame of reference of the detector,

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(ii) the frame of reference of the protons.

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(b) (i) Calculate the kinetic energy of each proton in the beam, in J.

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(ii) The beam consisted of 10^7 protons. It passed through the detector and was stopped by a stationary target. Calculate the average power which the proton beam delivered to the target during the pulse.

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(5)
(Total 8 marks)

3. (a) Michelson and Morley attempted to detect absolute motion by investigating whether or not the speed of light in a direction parallel to the Earth's motion differs from the speed of light perpendicular to the Earth's motion.

Discuss what resulted from this experiment and what was concluded.

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(b) In a science fiction story, a space rocket left the Earth in 2066 and travelled out of the Solar System at a speed of 0.80*c*, where c is the speed of light in vacuo, to a star 16 light years from the Earth.

(i) How many years, in the frame of reference of the Earth, did the spacecraft take to reach the star?

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(ii) What was the distance, in the frame of reference of the spacecraft, between the Earth and the star?

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(iii) A member of the crew was 21 years old on leaving the Earth. How old was this person on arrival at the star?

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(6)
(Total 9 marks)

4. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(i) Explain what is meant by this postulate.

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(ii) State and explain the other postulate.

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(4)

(b) A stationary muon has a rest mass of 1.88×10^{-28} kg and a half-life of 2.2×10^{-6} s.

Calculate

(i) the mass of a muon travelling at 0.996 *c*, where *c* is the speed of light in a vacuum,

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(ii) the distance, in a laboratory frame of reference, travelled in one half-life by a muon moving at 0.996 *c*.

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(6)
(Total 10 marks)

5. (a) The speed of an object cannot be greater than or equal to the speed of light yet its kinetic energy can be increased without limit. Explain the apparent contradiction that the speed of an object is limited whereas its kinetic energy is not limited.

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(3)

(b) Protons are accelerated from rest through a potential difference of 2.1×10^{10} V.

(i) Show that the kinetic energy of a proton after it has been accelerated from rest through this potential difference is 3.4×10^{-9} J.

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(ii) Show that the mass of a proton with the kinetic energy value calculated in part (a) is approximately 23 m_0, where m_0 is its rest mass.

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(4)

(c) Calculate the speed of a proton which has a mass equal to 23 m_0.

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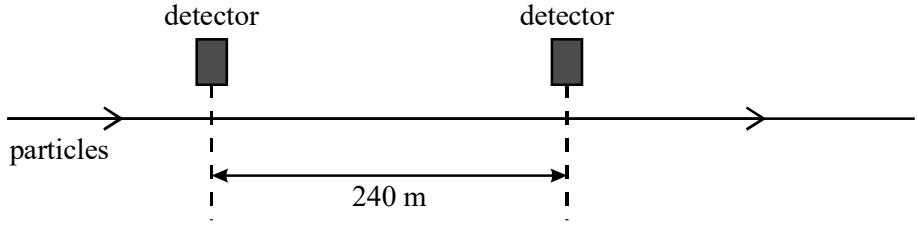
(3)
(Total 10 marks)

6. (a) In a particle beam experiment, a short pulse of 1 ns duration of particles moving at constant speed passed directly between 2 detectors at a fixed distance apart of 240 m. The pulse took 0.84 μs to travel from one detector to the other.



(i) Calculate the speed of the particles.

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(ii) Calculate the distance between the two detectors in the frame of reference of the particles.

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(4)

(b) In a 'thought experiment' about relativity, a student stated that a twin who travelled from the Earth to a distant planet and back at a speed close to the speed of light would be the same age on return as the twin who stayed on Earth. Explain why this statement is **not** correct.

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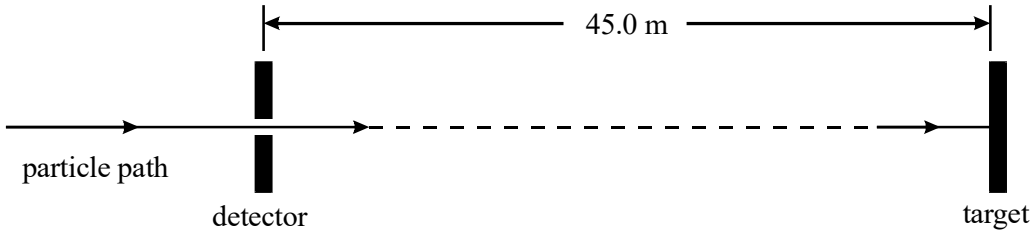
(4)
(Total 8 marks)

7. A particle passes through a detector and 152 ns later hits a target 45.0 m away from the detector.



(i) Calculate the speed of the particle between the detector and the target.

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(ii) Calculate the transit time of the particle from the detector to the target, in the frame of reference of the particle.

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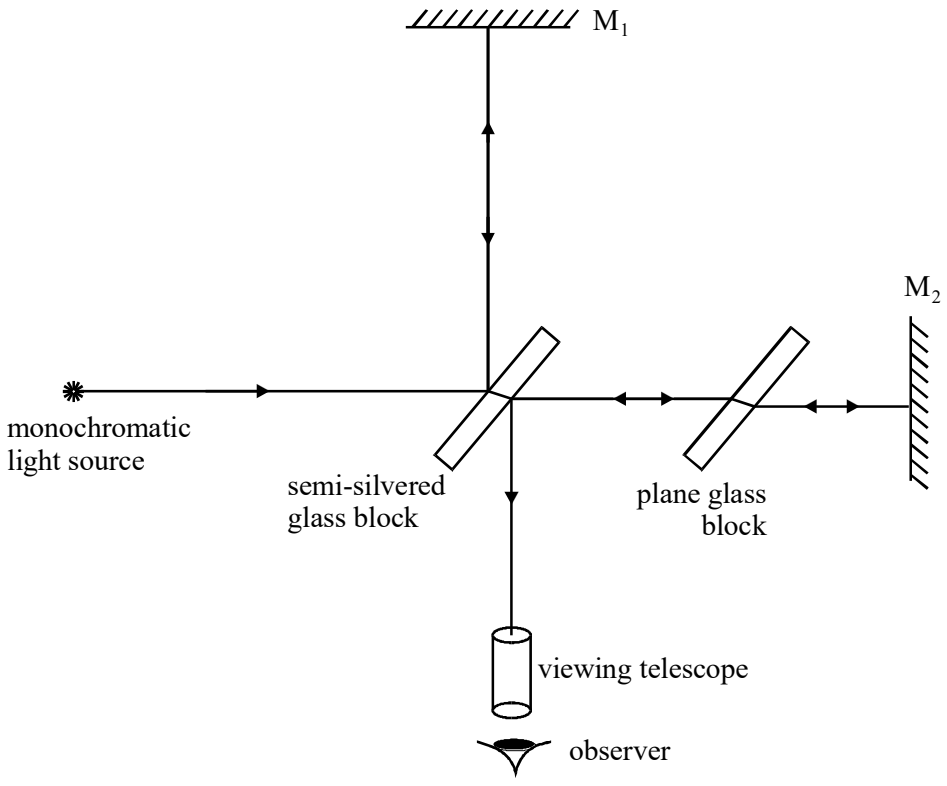
(Total 4 marks)

8. The Michelson-Morley experiment represented in the diagram was designed to find out if the speed of light depended on its direction relative to the Earth's motion through space. Interference fringes were seen by the observer.



(a) (i) Explain why interference fringes were seen.

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(ii) The interference fringe pattern did not shift when the apparatus was rotated by 90°. Explain the significance of this null observation.

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(5)

(b) Einstein postulated that the speed of light in free space is invariant. Explain what is meant by this postulate.

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(2)
(Total 7 marks)

9. (a) One of the two postulates of Einstein's theory of special relativity is that *physical laws have the same form in all inertial frames of reference*.

Explain, with the aid of a suitable example, what is meant by an inertial frame of reference.

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(2)

(b) A certain type of sub-atomic particle has a half-life of 18 ns when at rest. A beam of these particles travelling at a speed of 0.995*c* is produced in an accelerator.

(i) Calculate the half-life of these particles in the laboratory frame of reference.

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(ii) Calculate the time taken by these particles to travel a distance of 108 m in the laboratory at a speed of 0.995*c* and hence show that the intensity of the beam is reduced to 25% of its original value over this distance.

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(5)
(Total 7 marks)

10. (i) Calculate the kinetic energy, in J, of a proton accelerated in a straight line from rest through a potential difference of 1.1×10^9 V.

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(ii) Show that the mass of a proton at this energy is 2.2 m_0, where m_0 is the proton rest mass.

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(iii) Hence calculate the speed of a proton of mass 2.2 m_0.

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(Total 7 marks)

11. (a) In a science fiction film, a space rocket travels away from the Earth at a speed of 0.994 c, where c is the speed of light in free space. A radio message of duration 800 s is transmitted by the space rocket.

(i) Calculate the duration of the message when it is received at the Earth.

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(ii) Calculate the distance moved by the rocket in the Earth's frame of reference in the time taken to send the message.

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(4)

(b) A student claims that a twin who travels at a speed close to the speed of light from Earth to a distant star and back would, on return to Earth, be a different age to the twin who stayed on Earth. Discuss whether or not this claim is correct.

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(3)
(Total 7 marks)

12. (a) Calculate the speed at which a matter particle has a mass equal to 10 times its rest mass.

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(3)

(b) Explain why a matter particle can not travel as fast as a photon in free space even though its kinetic energy can be increased without limit.

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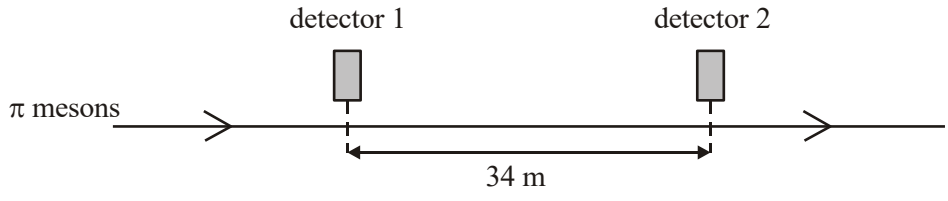
(3)
(Total 6 marks)

13. π mesons, travelling in a straight line at a speed of 0.95 *c*, pass two detectors 34 m apart, as shown in the figure below.



(i) Calculate the time taken, in the frame of reference of the detectors, for a π meson to travel between the two detectors.

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(ii) π mesons are unstable and decay with a half-life of 18 ns when at rest. Show that approximately 75% of the π mesons passing the first detector decay before they reach the second detector.

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(Total 5 marks)

14. (a) One of the two postulates of Einstein's theory of special relativity is that the speed of light in free space is invariant.

(i) Explain what is meant by this postulate.

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(ii) State and explain the other postulate.

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(4)

(b) A stationary muon has a rest mass of 1.9×10^{-28} kg.

For a muon travelling at a speed of 0.995 c, where c is the speed of light in a vacuum, calculate

(i) its mass,

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(ii) its total energy, in J.

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(iii) its kinetic energy, in J.

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(6)
(Total 10 marks)